Defence Research Establishment Pacific

Centre de recherches pour la défense pacifique

DEFENCE RESEARCH ESTABLISHMENT PACIFIC

CFB Esquimalt, FMO Victoria, B.C. V0S 1B0

DREP Technical Memorandum 93-83

The DREP/AT Side-Scan Sonar System (Preliminary Version)

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ABSTRACT

The Applied Technology (AT) section of the Defence Research Establishment Pacific (DREP) is developing a side-scan sonar system (the DREP/AT Sonar System) for use on an autonomous vehicle. A preliminary towed system was designed and tested in the spring and summer of 1993. It is comprised of some components of the Klein 595 Digital Sonar System, most of which have been modified, and custom modules designed in-house. This combination has produced a high-resolution, low-noise system that performs well as a towed side-scan sonar system. This paper describes the non-proprietary elements of the system, the modifications made to the Klein components, and the trial results.

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1.0 INTRODUCTION

The Applied Technology (AT) section of the Defence Research Establishment Pacific (DREP) is developing a side-scan sonar system (the DREP/AT sonar) for use on an autonomous underwater vehicle (AUV). This integrated system will allow covert mine-hunting or sea-floor mapping operations to be carried out inexpensively by an unmanned, submerged vehicle. This is a particularly useful activity for ensuring shipping security through potentially hostile waters, but is also practical for route survey work where the AUV, as a small vehicle, may be more versatile and accurate in its navigation, and therefore more efficient in sonar-mapping coverage, than a large vessel with a towed system. This phase of the project involves the development of the sonar system, and this paper discusses the design and testing of the first working prototype. Further research is needed to perfect this sonar system and to integrate it with the autonomous vehicle.

A low-power, self-contained recording system has been built around modified components from the Klein Digital Sonar Recorder Model 595 and Towfish [1]. The Klein system was used because DREP already owned one, and because the Klein 595 system is extremely modular in design, allowing core components to be easily extracted for use in the prototype system. Many modifications have been made to the original Klein components, and redesign of some essential circuits has been done for the DREP/AT system. Other Klein components will be replaced as the project progresses.

Preliminary tests of the DREP sonar system were made using a towed body during May, June and July of 1993 in a well known area near Esquimalt Harbour. This paper describes the system and the results of the trials.

The commercial Klein 595 system is comprised of a processor unit, a towcable, and a towed body (towfish). The processor contains all the system's power supplies, the trigger generator, the signal compression circuits (known as the time-varying gain or TVG circuits), the digitizers, the printer, and the operator interface. The towcable carries the power, trigger, and signals to and from the towfish. The towfish houses the transmission pulse generators, the preamplifiers, buffers, and the sonar transducer arrays (one facing port, and one starboard).

For the DREP/AT sonar system the transducer arrays, transmission pulse generators, and TVG circuits were extracted from the Klein 595 system. The power supply used in this DREP/AT prototype was taken from an older model Klein sonar system. The Klein 595 printer with its internal digitizers was used as a display and

paper-recording device. The trigger generator, preamplifiers, and buffers were replaced with in-house designs.

The details of these components and the prototype DREP/AT chassis are presented in the following sections.

2.0 TOWFISH LAYOUT

The 1993 version DREP/AT system layout is shown in Figures 1 and 2. The chassis was housed in an 21.6 centimeter (outer diameter) aluminum tube, with the endcap at the tail end of the towfish. The towfish was towed from the top, as shown in Figure 3.

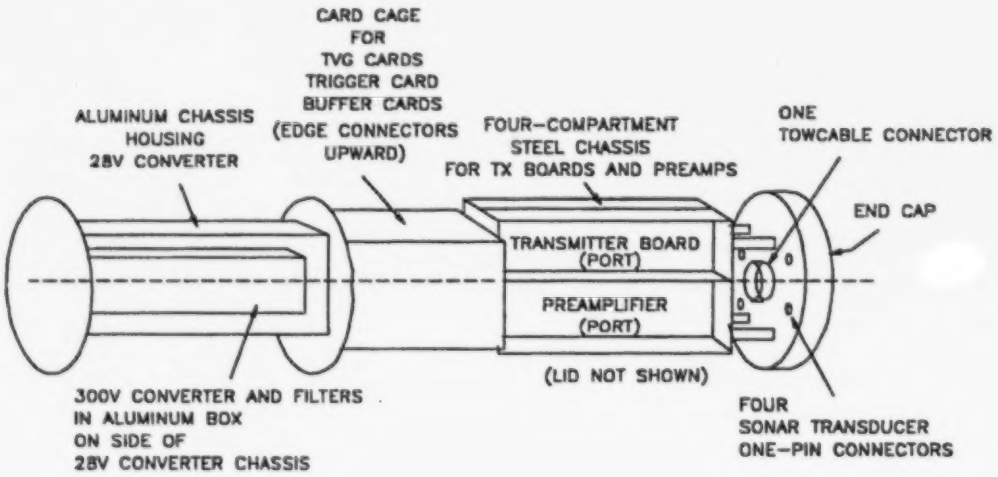


Figure 1: System Layout

The layout of the components significantly affects the noise characteristics of the system. Aluminum is a poor magnetic-shielding material, so each transmitter card and each preamplifier circuit was placed in a separate compartment of a steel box. All the power converters were placed at the back of the system, and we gave careful attention to eliminating ground-loops in the system, and to minimizing the length of all wiring, using twisted pairs, shielded twisted pairs, or coaxial cables wherever possible.

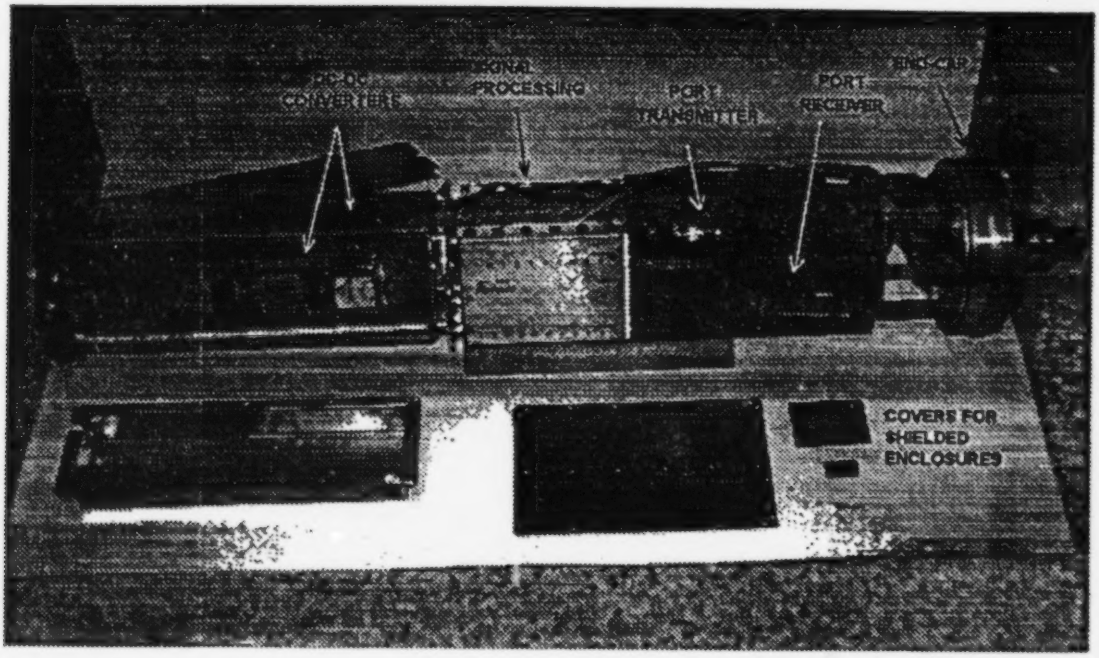


Figure 2: Photograph of the System

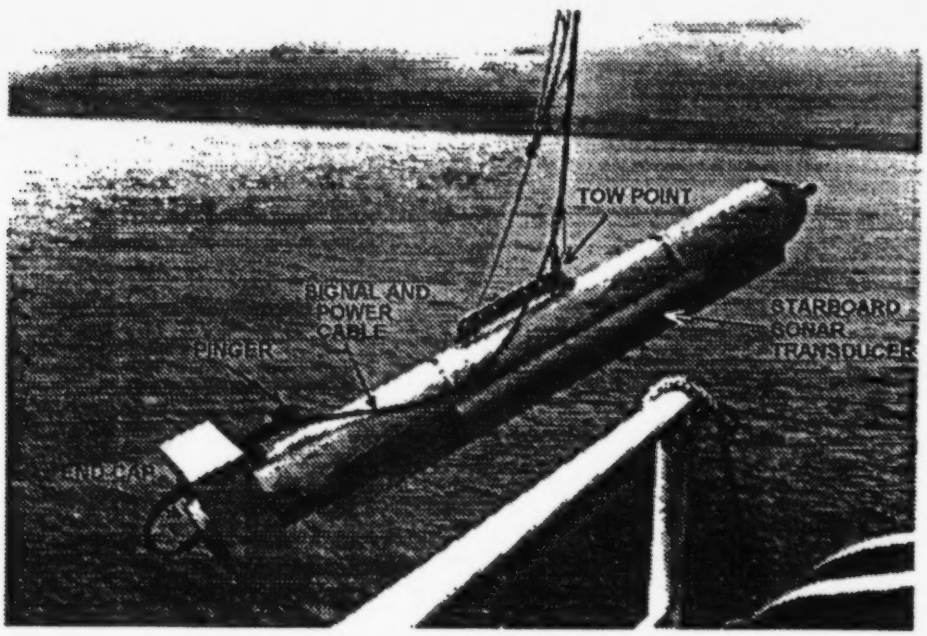


Figure 3: Exterior View of the Towfish

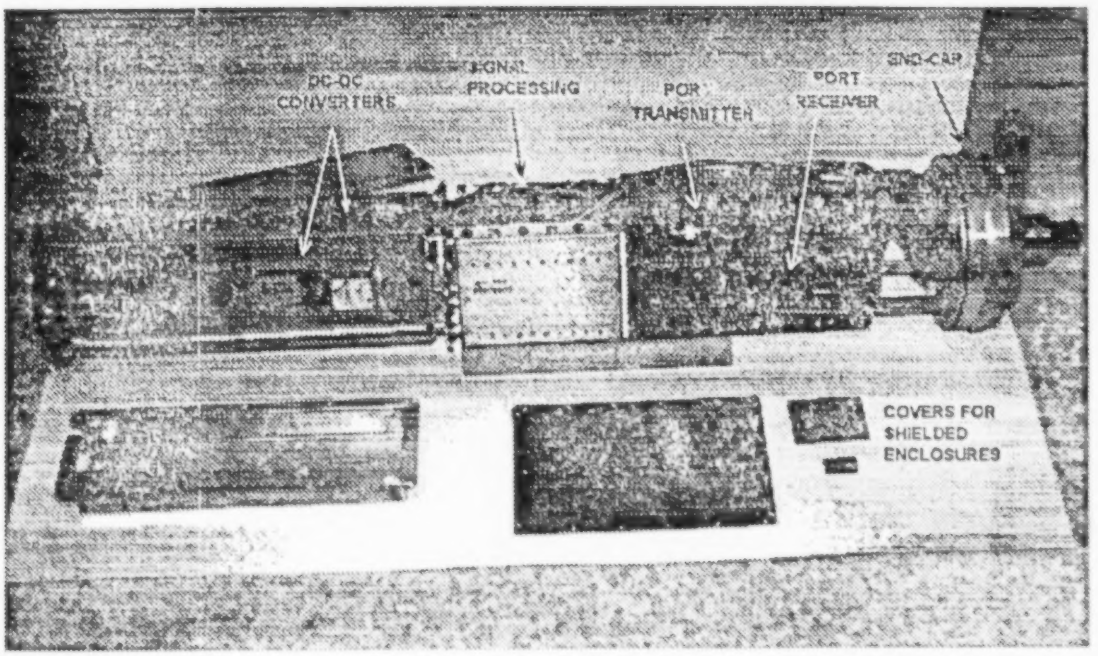


Figure 2: Photograph of the System

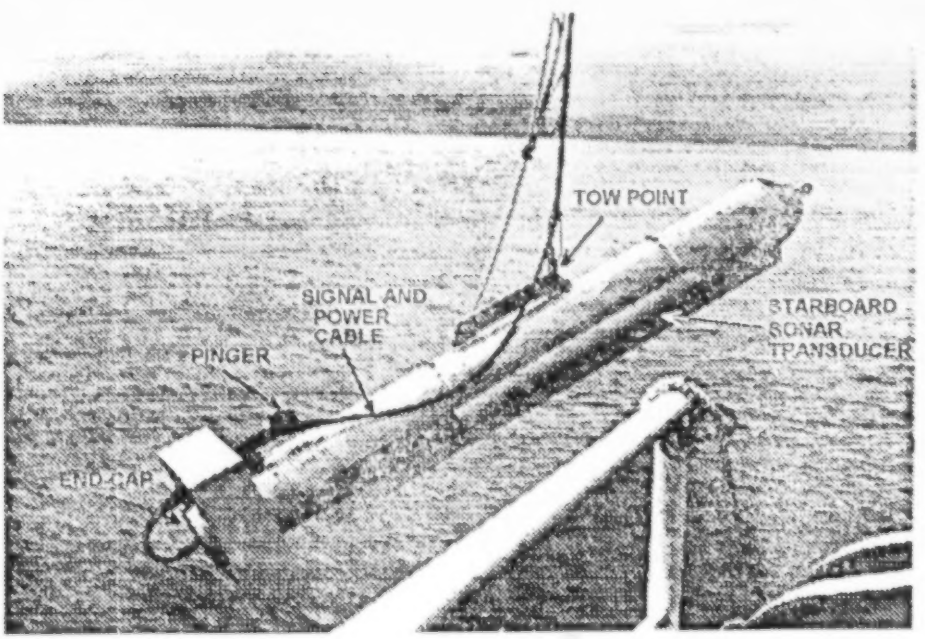


Figure 3: Exterior View of the Towfish

3.0 SYSTEM DETAILS

3.1 Power Supplies

The power supplies proved to be the most challenging part of the design because of the noise introduced by the switching power supplies and their location in this system in close proximity to the sensitive sonar preamplifiers. We used a 300 VDC Sorensen (DCR-300-3B) supply to power the towfish electronics from the ship. This high voltage was used to reduce resistive losses in the 1000 meter towcable. The high voltage was converted to 28 VDC in the towfish by a Vicor VI-26L-CU converter and filters. The corresponding Vicor output filter was not available before the trials, so we substituted a Corcom EMI filter (designed for filtering 120 VAC, 60 Hz power lines) as a temporary replacement. (Its effectiveness as a filter in this configuration has not been determined.) The schematic is shown in Figure 4:

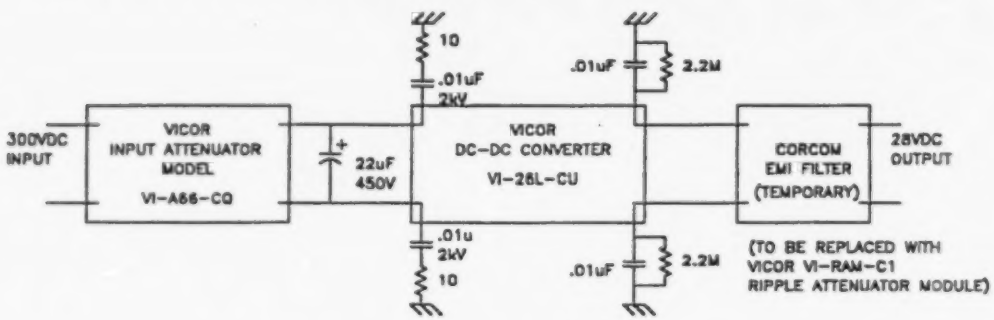


Figure 4: 300 VDC to 28 VDC Converter

The 28 VDC produced by this converter was used to power a multiple-voltage switching power supply (Model 196-B) taken from a Klein 531T Side-Scan Sonar system. We used this supply because it provided an immediately available source of all the voltages required for the system. This power supply converts 28 VDC to ±15 VDC at 400 mA each, 5 VDC at 1 A, and 750 VDC at 53 mA. The supply is very noisy and switches at 20 kHz, which puts harmonics throughout the signal band.

Minor modifications were made to this supply to reduce noise: 470 uF electrolytic capacitors were added from each output to ground for filtering, and protection diodes were wired from the output of each voltage regulator to its input (to safely drain the energy of the added capacitors when the input power is removed). To improve electromagnetic shielding, the aluminum side-plates of this Klein power supply were replaced with steel panels.

The return line of each voltage produced by the 196-B supply is internally connected to all the others; to reduce noise we connected this common line to the towfish chassis, which is shorted to the ocean during operation. Grounding the electronics to the ocean can cause various problems, because of signal returns through the ocean to the ship electronics, but we found this to be an effective cure for the noise problems in this particular situation.

Careful filtering, shielding, wiring, and layout of the power supplies in this system were required to reduce the noise to a usable level. In the laboratory, the system, not including the towcable buffers or the recording system, drew 1.3 A_{rms} at 24 V, which is 31 watts.

3.2 Transducer Arrays

For these trials, two Klein sonar transducer arrays of the same frequency were used: one pointing to the port side of the towfish, and the other to starboard. The Klein system has sonar arrays for two frequencies of operation: approximately 350 kHz, and 117 kHz.[1] These arrays have a very narrow beamwidth in the plane of the ocean floor, and a very wide beamwidth in the vertical plane. Theoretical analysis of the beam pattern [2] indicates that the near-field region extends for 18 meters with the 350 kHz

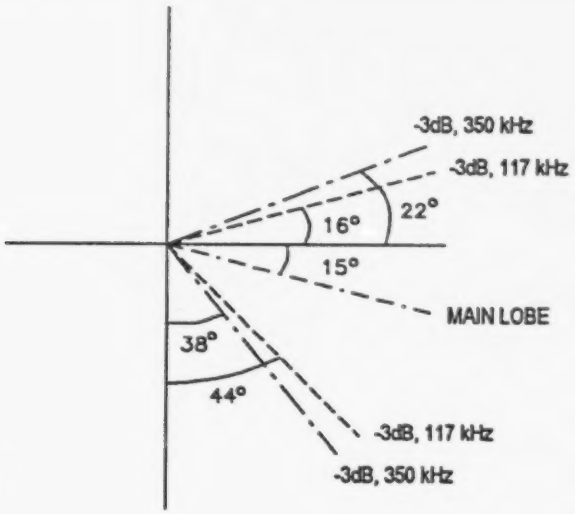


Figure 5: Sonar Beam Direction at Recommended Mounting Angle

[1]The frequency varies somewhat with time during each transmitted signal and each transducer array has a slightly different average frequency. This is the mean value measured for the DREP transducers, in air, at the input to the preamplifiers.

arrays, and 5 meters with the 117 kHz arrays. The analysis also indicates the horizontal -3 dB beam angle[2] for the 350 kHz transducer arrays is 0.5°, and for the 117 kHz arrays is 1.7° and the vertical beam angles are 74° (350 kHz), and 62° (117 kHz).

The narrow beamwidth along track (parallel to the ship and towfish path) allows for excellent resolution of small objects. The wide beamwidth in the vertical plane, while necessary to ensonify long ranges, caused problems, because noise and reflections from the surface of the ocean were strongly received by these arrays. See for example Figure 17. The transducers could be aimed lower (see Figure 5) or some form of shielding that will not interfere with the hydrodynamic stability of the vehicle could be designed to block the transducer arrays from the ocean surface returns.

The electrical signals from the transducer arrays are amplitude-modulated suppressed-carrier signals, whose amplitudes vary from ±.8 V maximum (diode clipped) down to tens of microvolts. The attenuation of the signal with time depends upon spreading losses, the frequency, and the scattering properties of the ocean floor, but is sufficient that signal compression with time is required to effectively record the sonar signals.

3.3 Transmitter

Each transducer array in this system is connected to a Klein transmitter circuit. The transmitter circuit receives a low voltage (5-12 V) trigger pulse, and discharges a high-voltage-charged capacitor through a step-up transformer. The secondary side of the transformer is connected to the electrodes of the transducer array. The transducer array, under the effect of the high-voltage pulse, distorts and mechanically rings for a period that depends upon its design and loading, producing a broadband sound pulse.[3]

We modified each Klein transmitter-cards to reduce its susceptibility to noise, to separate the trigger line from the 15 VDC supply line, and to replace the original preamplifier with a new design. The printed-circuit-board common trace was replaced with a low-resistance cable. The common of the secondary side of the transformer was separated from the primary-side common, and reconnected through a pair of anti-parallel diodes, to break the ground loop that occurs because the 15 V supply powers

[2]All beam angles referred to here are the angle between the two -3 dB contours, not from beam center to the -3 dB contour.

[3]This is referred to as broadband because the energy is spread over more frequencies than when the transducer arrays are driven by a gated sine-wave, or "tone-burst" driver.

both the transmitter card circuitry on the primary side of the transformer, and the preamplifiers on the secondary side of the transformer.

We made one further modification to the transmitter cards: for part of the trials we replaced the 1.0 uF capacitors in the 117 kHz transmitter circuits with 0.22 uF capacitors. We assumed that this would result in a shorter transmitted pulse length.

The transmitted pulse length affects how much absolute energy is available, and how resolved the sonar image will be across the track (perpendicular to the towfish path). Along-track resolution is determined by the beamwidth, which is not affected by the change in capacitance, since it is a function only of transducer array dimensions and frequency. With the smaller capacitors we expected the signals to be somewhat weaker, but more resolved across the track at all ranges.

Experimentally the pulse length at the receiver was measured with the protection diodes in place, so the time from the trigger until the diodes were no longer clipping the transmit pulse was the only available measure of transmit-pulse length. By this measure the 0.22 uF capacitor resulted in a pulse length that was about half the length of that produced with the 1.0 uF capacitor.

The effects on the sonar images of changing the transmitter capacitor are discussed in Section 4.0.

3.4 Preamplifier

Quiet, narrowband, differential-input preamplifiers were designed by DREP to replace the Klein preamplifiers. The choice of system bandwidth trades off the reduced system noise obtained as the bandwidth is decreased, with the potential loss of signal energy and information. Limiting signal bandwidth also reduces the required storage space (since the digitizing rate can be reduced), and this is a factor in surveys where all the data must be kept for post-processing or archiving. In this system, the preamplifier bandwidth was chosen to be 140 kHz for the 350 kHz system and 75 kHz for the 117 kHz system. The gain was adjustable with jumpers, but we found that a gain of 60 dB was best. A three decibel difference between the gain of the two 117 kHz arrays, was corrected by increasing the preamplifier gain to 63 dB for the weaker array. The schematics of the preamplifiers are shown in Figures 6 and 7.

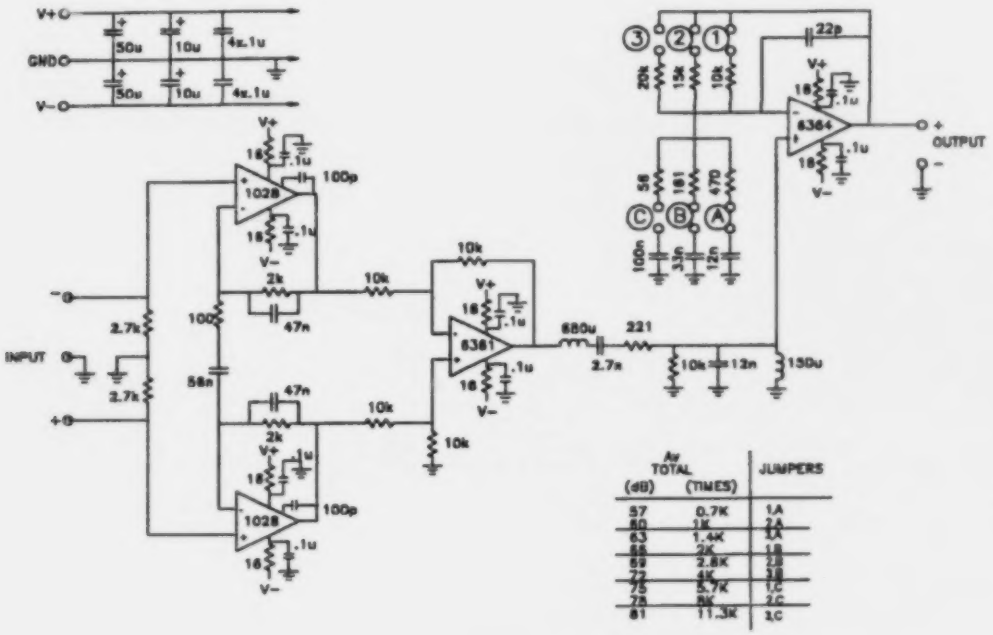


Figure 6: 117 kHz Preamplifier

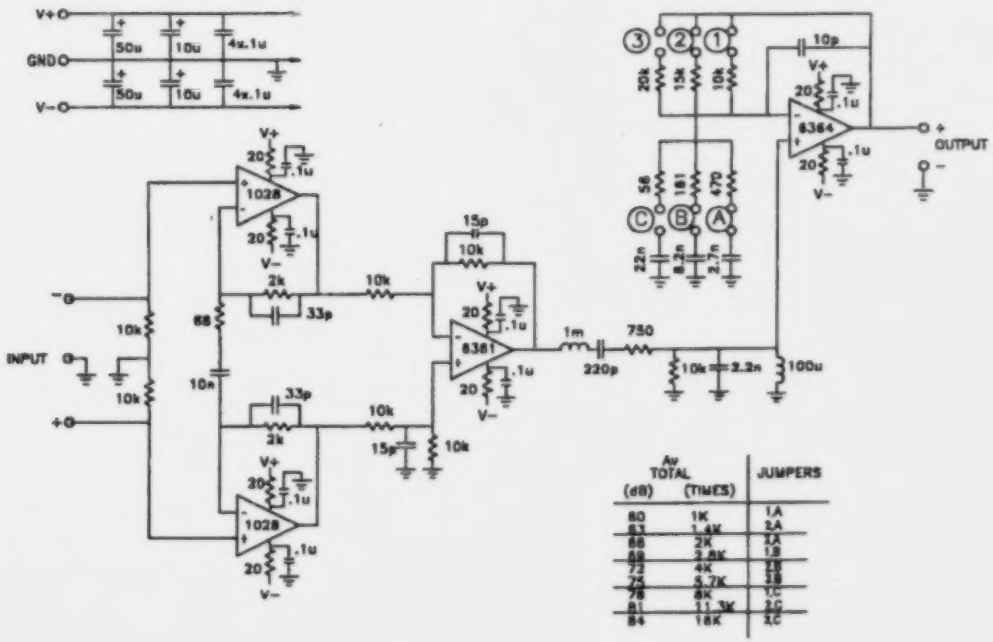
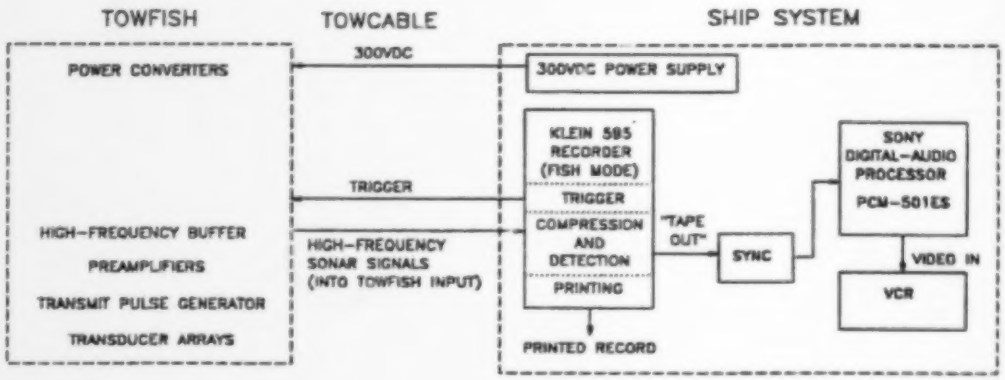


Figure 7: 350 kHz Preamplifier

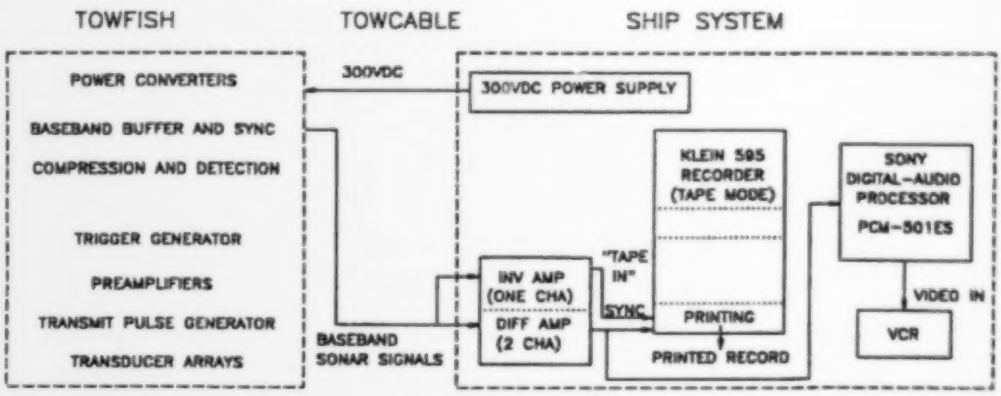
3.5 The Klein 595 Recorder

The Klein 595 Recorder (the processor section of the commercial Klein 595 system) can be used in two different modes. The "Fish" mode is its normal operating state: the Klein Recorder accepts uncompressed high-frequency sonar signals from the towfish and processes them internally, producing a printed record and compressed baseband output signals for tape recording. In this mode the Klein Recorder produces the system trigger.

In the "Tape" mode the Klein Recorder acts just as a printer. It receives an external trigger and precompressed, baseband, sonar signals, and it prints the signals. Figure 8 shows block diagrams for the two configurations.



(a)



(b)

Figure 8: System Configurations Used in Trials, (a) First Configuration--compression and detection on the ship, and (b) Second Configuration--compression and detection in the towfish.

In these trials the Klein Recorder was used in both configurations. We ran the system in Fish-mode (Figure 8a) so that we could vary the compression parameters during operation, to determine the best values to use in this system. Once the parameters for the compression system were set, the processing was all moved into the towfish (Figure 8b), and the Klein Recorder was run in Tape-mode.

In the trials we found the first configuration to be very ineffective with the 350 kHz signals, for two reasons. First, the towcable loss is excessive at this frequency, as is seen from the graph in Figure 9, which shows the towcable characteristics measured at several frequencies. Second, there was a problem with inter-cable coupling: the amplified high-frequency signals being transmitted up the towcable, radiated from the unshielded (towfish) end of the towcable, into the nearby transducer-array cables, and were reintroduced to the preamplifiers. The effect was severe crosstalk, where strong reflectors on one channel appeared on the other channel.

There were no problems running the 117 kHz system in either mode.

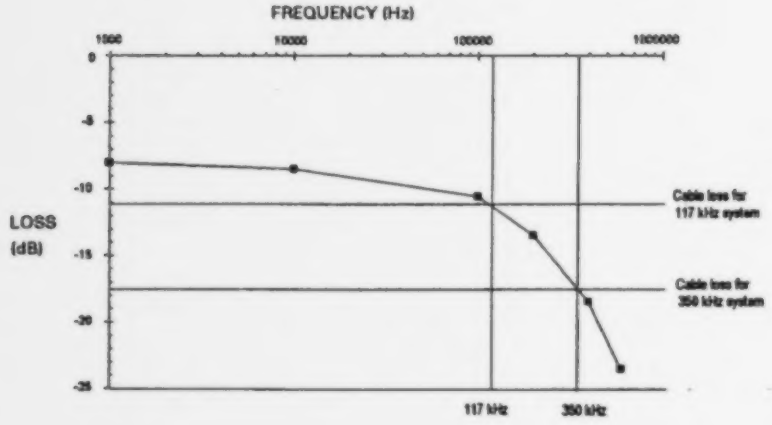


Figure 9: Frequency Characteristics of the DREP 1000-meter Towcable

3.6 Triggering and Synchronization

The system trigger tells the Klein Recorder when to begin printing a new line, and the transmitter cards when to fire the transducers. It is also used to generate a synchronization pulse for recording, which enables a stable trigger to be recovered when the signals are played back from tape.

The trigger is a simple 1 millisecond, 5 V pulse, generated either by the Klein 595 Recorder, operating in Fish-mode, or by the circuit of Figure 10 in the towfish when the Klein Recorder is operating in Tape-mode. The circuit of Figure 10 provides a simultaneous 15 V pulse for transmission up the towcable, but this amplification was found to be unnecessary.

Trigger recovery from tape-recorded signals is enabled by multiplexing a synchronizing pulse on the sonar signals before recording. This is accomplished by inverting and adjusting the amplitude of the trigger pulse, and using a switch to replace the initial millisecond of each sonar signal with this inverted pulse. (The initial millisecond of a side-scan sonar signal does not contain useful information.) The circuit of Figure 11 was used in the towfish for this purpose. The same circuit, without the buffers, was used on the ship, when the signals were processed there.

The trigger could have been transmitted up the towcable directly, to synchronize the printer, but simply inverting the sonar signal from either channel, and amplifying it to raise the synchronizing pulse to 5 V, was sufficient to trigger the Klein 595 Recorder. A simple inverting amplifier was used to provide the trigger for the printer (recovered from the sonar signals) during the trials, and also later when playing back the taped signals. This eliminated the need to transmit a trigger up the towcable on a separate signal line.

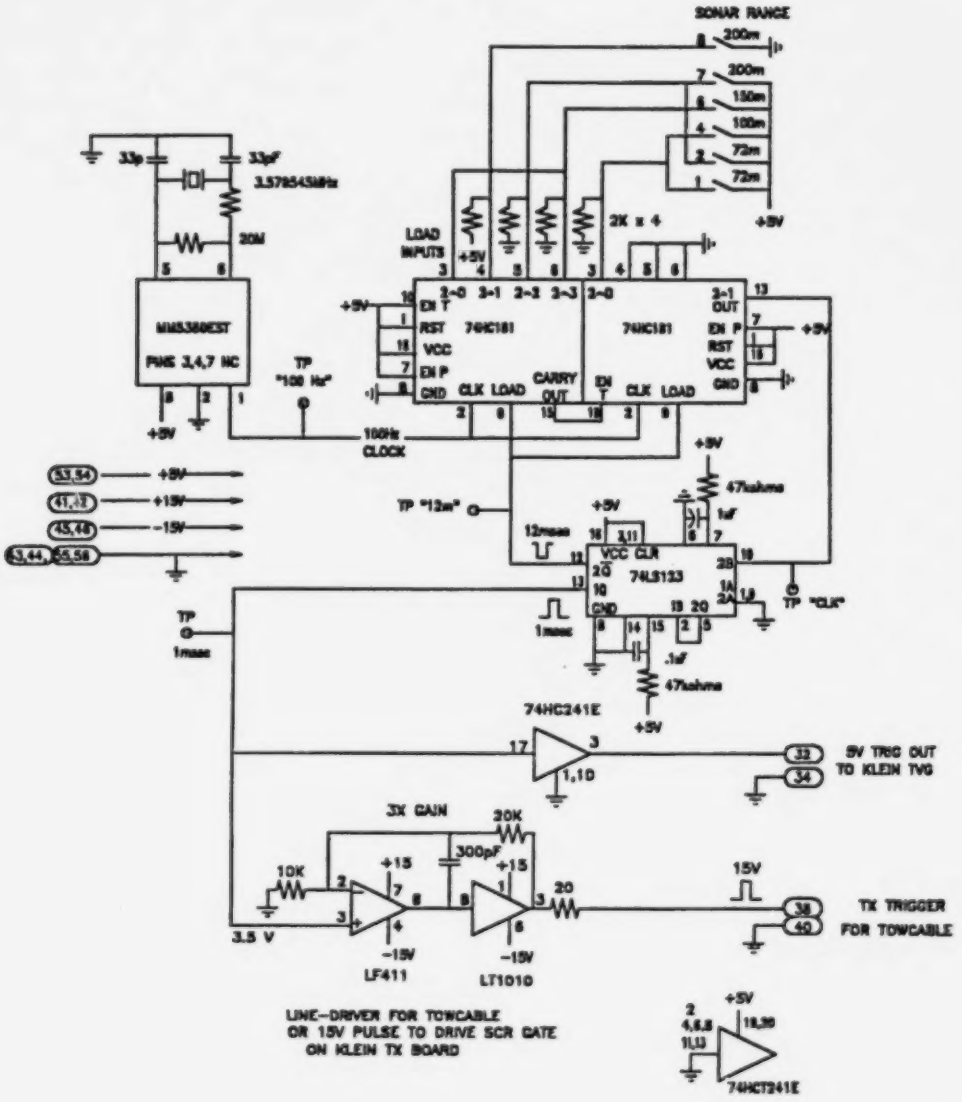
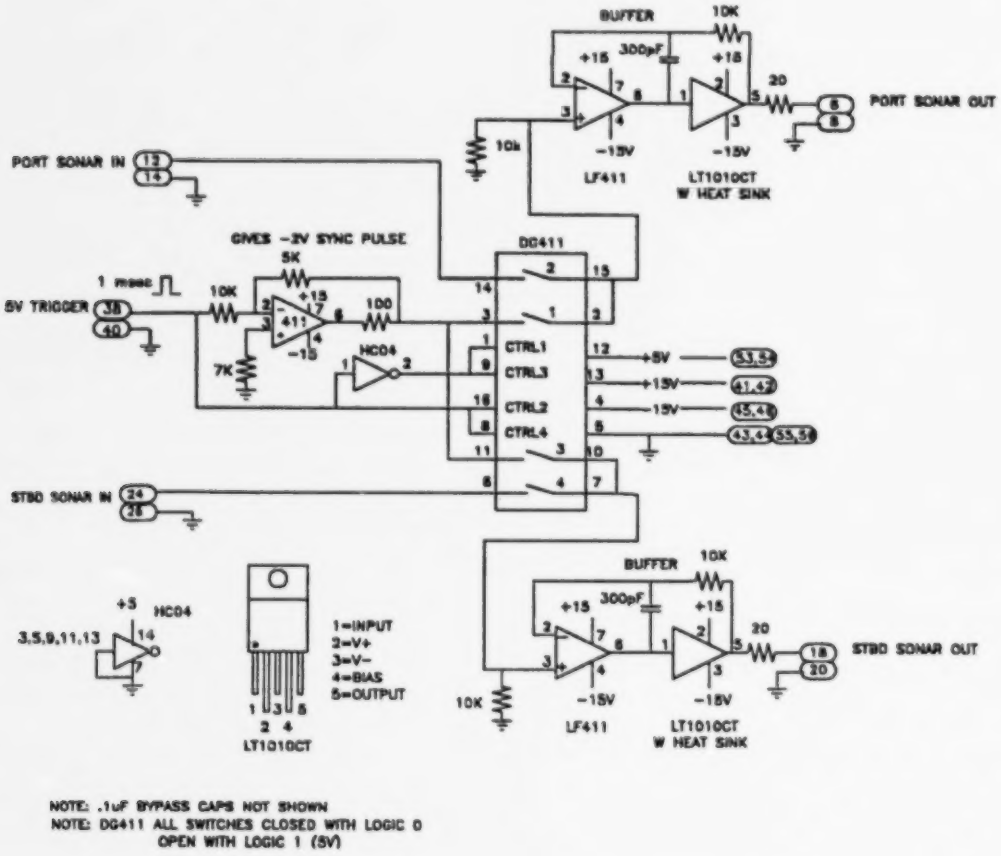


Figure 10: Trigger Generator Circuit



NOTE: .1uF BYPASS CAPS NOT SHOWN
NOTE: DG411 ALL SWITCHES CLOSED WITH LOGIC 0
OPEN WITH LOGIC 1 (5V)

Figure 11: Baseband Buffer and Synchronization Circuit

3.7 Buffers

For the first configuration, the circuit whose schematic is shown in Figure 12 was used to buffer the high-frequency signals for transmission up the towcable. The signals were immediately sent to the Klein 595 Recorder for processing.

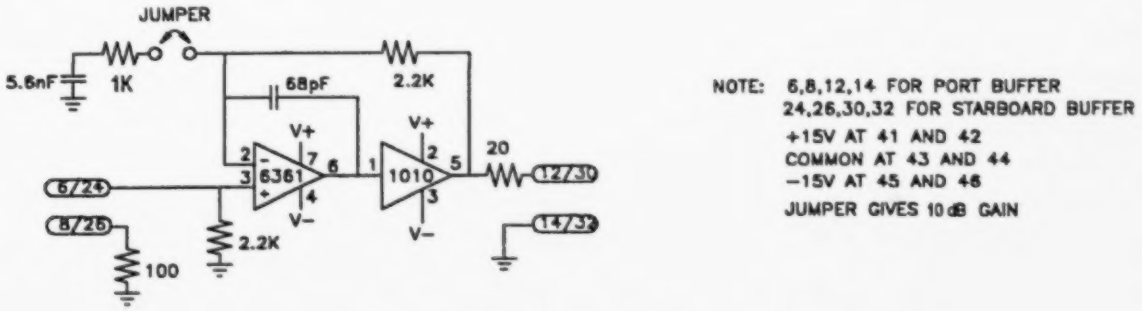


Figure 12: High-Frequency Buffer

In the second configuration, the preamplified sonar signals were converted to baseband in the towfish, and transmitted with the buffer shown previously in Figure 11. This low-frequency buffer circuit also applied the synchronization pulse described earlier.

At the ship-end of the towcable the baseband signals from the towfish were sent to a differential receiver whose schematic is shown in Figure 13. From the differential receiver they were routed to the Klein 595 Recorder for printing, and to the tape-recording system described in Section 3.9.

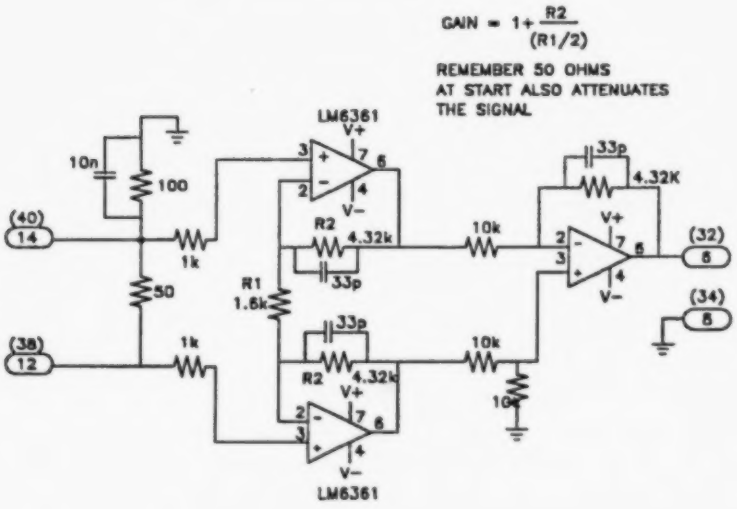


Figure 13: High-Frequency Differential Receiver

The gain of the differential-receiver is given by $G=1+(2R_2/R_1)$, not taking into account attenuation caused by the 50 ohm input resistor (the 50 ohm input resistor can be removed if it is not required for matching the impedance of the circuit to the impedance of the cable). With the values shown the gain is 6.4 times. The input low-pass filter as shown is set for a cut off of approximately 350 kHz (with the 50 ohm input resistor in place). This circuit was also used (without the 50 ohms) as a stable amplifier when playing back the taped signals into the Klein 595 Recorder for printing.

The differential receiver was used to eliminate ground-reference problems between the towfish circuits and the ship-board circuits.

3.8 Signal-Amplitude Compression

The amplitude compression of the sonar signals was done by modified Klein TVG (time-varying gain) circuits, which are part of the Klein 595 Recorder system. Time-varying gain is required for sonar signals, because the attenuation with time caused by energy loss in the water results in a received signal with a very wide dynamic range. The Klein TVG system is comprised of three circuit boards: one controller ("AUTO-CPU"), which computes the gains to be applied to compress the sonar signals, and one analogue circuit board ("AUTO-TVG") for each channel of sonar data. The circuit on this latter board compresses the sonar signal and converts it to baseband.

The advantage of sending the high-frequency, uncompressed sonar signals up the towcable is that the Klein TVG circuits have numerous values that the operator can adjust through switches on the circuit boards. Each switch can set its corresponding variable to "automatic mode" or to a fixed value. In "automatic mode" the TVG software determines, and continually recalculates the variable's value, according to the current levels of the received sonar signals. Otherwise the program uses the values set by the operator as constants in its calculations. While this system was designed by Klein to run automatically using sophisticated software to optimize the signals for printing and magnetic-tape recording, we made certain hardware changes to the circuits that significantly affect the signal levels. We substituted higher speed, unity-gain-stable integrated-circuit amplifiers (LM6361) for the ones which were processing high-frequency signals, and removed the capacitors that were required to stabilize the original amplifiers.

Since the software had been designed by Klein to optimize the printing of the slew-limited signals, we were concerned that the TVG system might not adapt automatically to the much wider dynamic range of the signals now present, and we found this to be true in the trials. The best manual settings were determined with the

compression system on the ship, and the switches were set to these values before the boards were installed in the towfish.

In addition to changing the integrated-circuit amplifiers, the input filters were removed from the TVG cards, since band-limiting filtering is applied by the DREP preamplifiers.

3.9 Recording System

After the signals were compressed and detected, either on the ship or in the towfish, the synchronization pulse was applied, as explained earlier. The synchronized baseband sonar signals were then digitized and coded by a Sony Digital Audio Processor (PCM 501-ES), and recorded on VCR tape. The Sony Processor digitized and multiplexed the port and starboard sonar signals, and converted the result to a single NTSC[4] signal for recording on the video channel of a standard commercial video-cassette recorder. The VCR tapes were recorded at standard speed, allowing two hours of recording per tape. (One or both of the hi-fi audio channels of the VCR tape are normally used in DREP side-scan sonar trials to record 9600 baud modulated[5] navigation data. No such data was available on these trials, so nothing was recorded on the hi-fi channels.)

4.0 RESULTS

The Targets

Two different sonar targets are considered here: the first is a target specifically designed and built at DREP to test the resolution of sonar systems. It was deployed in the summer of 1993 shortly before the trials. Figures 14 through 16 show details of this resolution target. Figure 14 shows the top face of the target with the wooden balls forming an arrow, Figure 15 shows the frame which is attached to the underside of the target, and Figure 16 gives the relative dimensions of the complete target.

[4]National Television System Committee format, that is, the normal North American television-signal format.
[5]If a commercial modem is to be used to modulate the data the purchaser must be aware that most high speed modems are designed to expect feedback from another modem on the other end of the line. It is necessary to use a modem which can run without such feedback for tape recording. DREP uses the Gandalf LDS 309A modem [3] for this purpose.

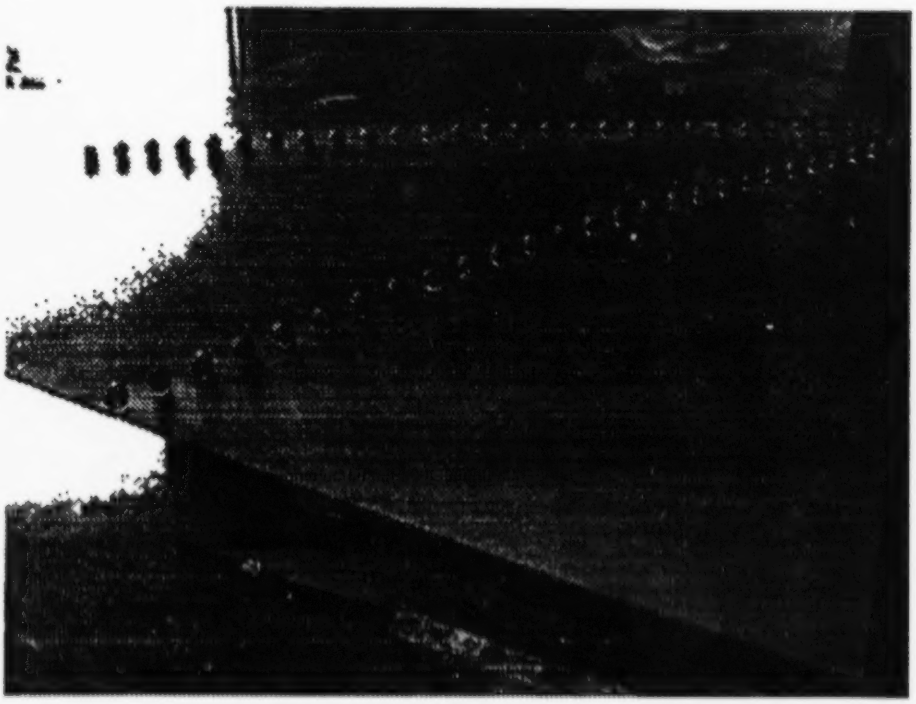


Figure 14: The Resolution Target

The resolution target is constructed of 2 centimeter thick PVC (polyvinyl chloride) sheet, 244 centimeters on each side, with a large arrow comprised of 56 five-centimeter wooden balls spaced every ten centimeters glued to the PVC sheet. A large metal frame was attached to the underside for weight. This frame is constructed of 1.2 meter long, 13 centimeter I-beams, formed into a square, with additional weights attached to the inside center of each side. The entire target was painted to inhibit growth.

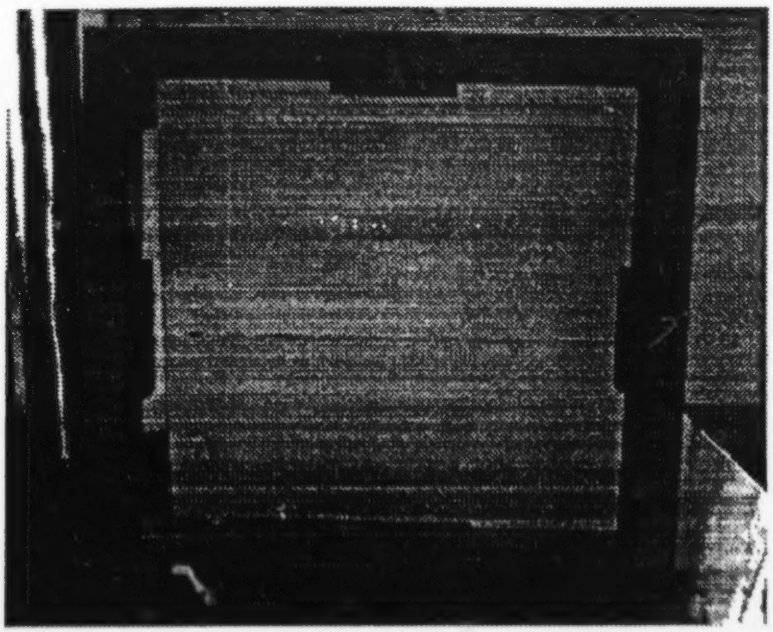


Figure 15: Photograph of the Resolution-Target Frame

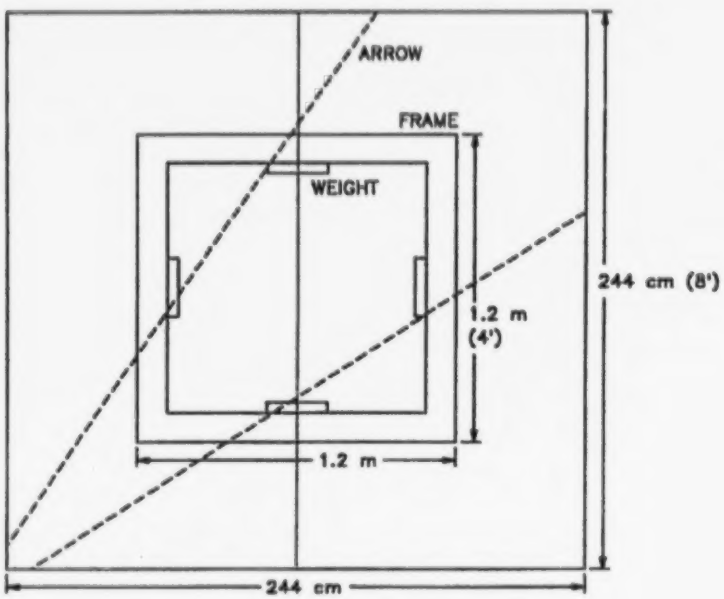


Figure 16: Resolution-Target Dimensions

The second target is the sunken remains of a 55 meter long ship, which provides a large, detailed target, with a large shadow. The large shadow is useful for testing system noise.

The Sonar Images

The sonar records shown here in Figures 17 through 25 were printed on the Klein 595 Recorder System using signals from the VCR tapes recorded during the trials. The images are negative, that is, strong signals returns are black and low signal levels (shadows, for instance) are white. Signal amplification was provided as required between the recording system output and the Klein 595 Tape Input, using the circuit of Figure 13 with the 50-ohm input resistor removed, and R1 of either 0.8 or 1.6 kilohms, giving gains of 11.8 or 6.4 times, respectively. The printed records were then scanned into a computer, using an HP Scan Jet IIc, and then printed on a HP LaserJet III printer. The scale lines on the printed records (the periodic thin lines) are ten meters apart. The towfish was typically ten to fifteen meters above the ocean floor, except when surveying very long ranges (150 meters or more) where the towfish was kept at a higher altitude.

Beam Spreading of the 117 kHz Sonar

Before looking at specific targets, we should consider Figure 17, which shows the effect of beam spreading in the 117 kHz system. The large black line running down the center of the image is the reflection of the sound from the ocean surface. The hemispherical half-black, half-white objects are mounds of gravel deliberately placed on the ocean floor. The two square shapes are frames made of 10-centimeter diameter PVC pipes. (One is just past the surface return, before the two distant gravel mounds.) There are a few fish, whose air-bladders are visible as black specks above the ocean floor.

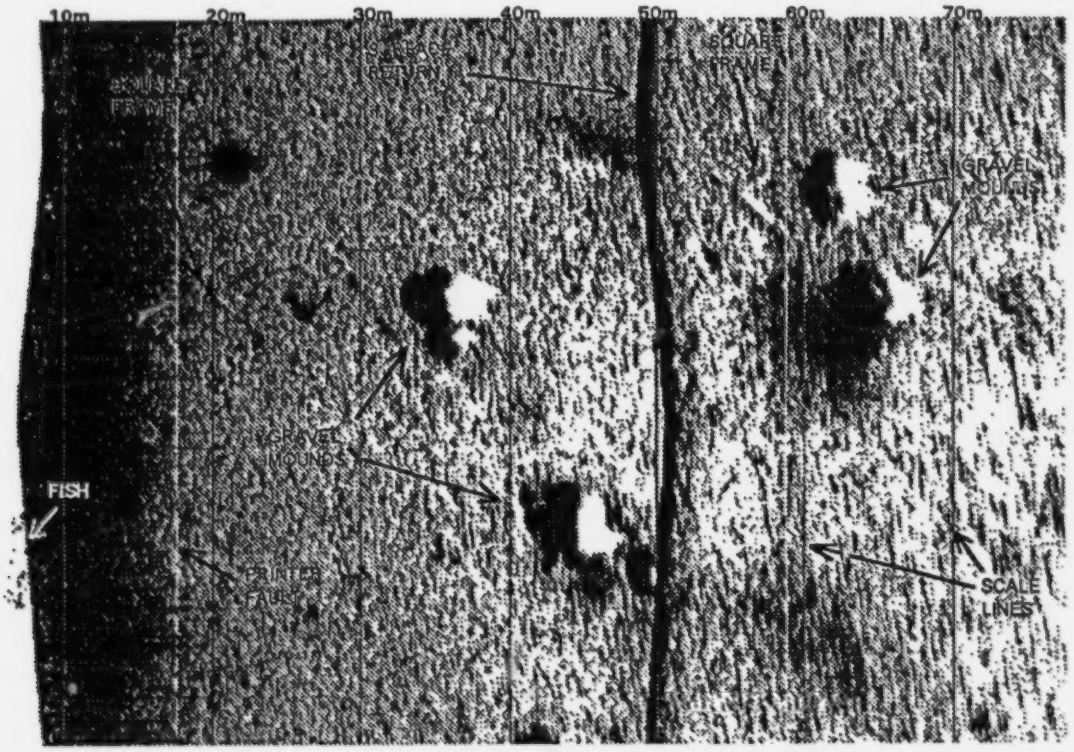


Figure 17: Beam-Spreading Effects of the 117 kHz Short-Pulse System

The presence of the gravel mounds past the surface return allows us to see that the streaking is not caused by noise from the ocean surface, because the shadows of the mounds are clean white. The spreading is along the track, rather than across the track, because the wider horizontal beamwidth at longer ranges ensonified and received energy from distant reflectors before and after the transducer array passed them, whereas near reflectors were in the beam only for the moment the transducer was directly opposite them. (Spreading across track would have occurred only if the pulse became longer with distance.)

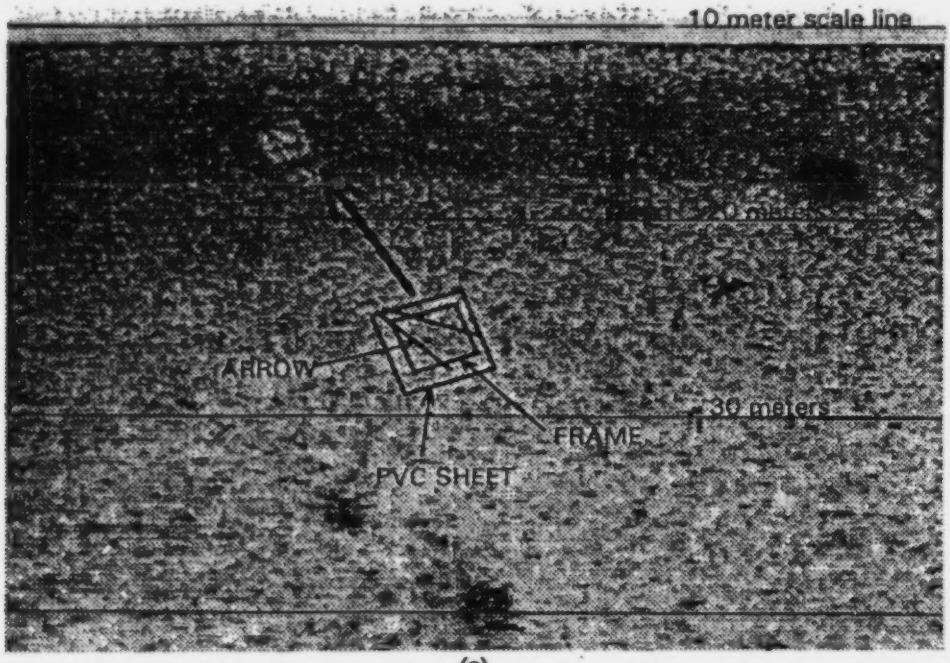
The Resolution Target Images

Figures 18, 19 and 20 show the sonar record of the DREP resolution target taken with the 117 kHz long-pulse (original capacitor) system, the 117 kHz short-pulse (smaller capacitor) system, and the 350 kHz system, respectively. Notice that Figures 18b, 19b,

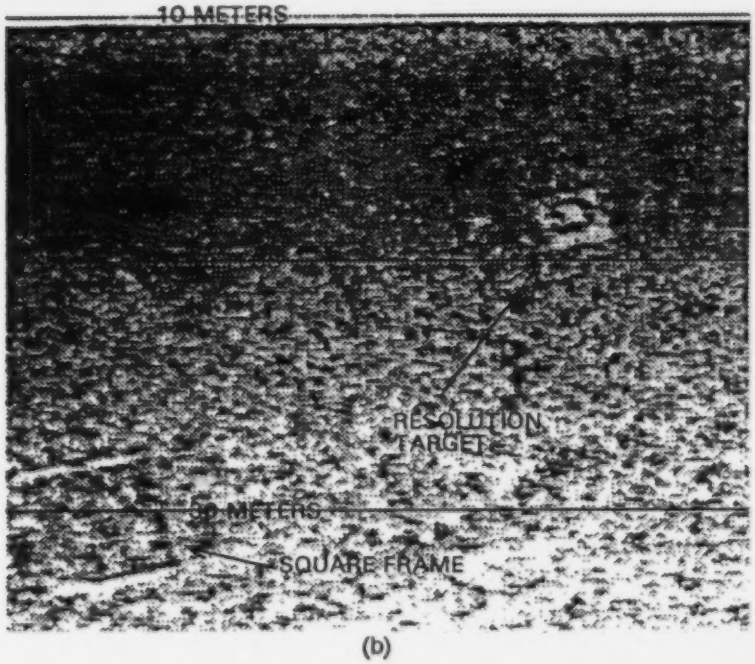
and 20 were taken with the maximum range set to 75 meters, whereas 18a and 19a were taken with the maximum range set to 100 meters.

The resolution target shows clearly on these sonar records as a white square with a black arrow, at both low and high frequencies. There was more penetration of sound through the target at 117 kHz than at 350 kHz, resulting in a darker image in the area of the PVC panel for the lower frequency system. Since the sound penetrated the target at 117 kHz, and not 350 kHz, the resolution target's metal frame is clearly visible in Figures 18 and 19, but not in Figure 20.

The reflectivity of the wooden balls is not angle or range dependent, so as the distance to the target increases, the brightness of the arrow decreases. The visibility of the frame in the low-frequency images seems to be dependent upon the incident angle; it shows up more clearly at longer ranges, corresponding to more shallow angles of incidence. A careful examination of the images shows that it is not really the whole I-beam that forms the bright return signal, but rather the corners where the I-beams are welded together (the corners of the frame), and the corners formed between the I-beam and the extra weights that are attached to the inside center of each beam. Corner reflectors form bright returns because they reflect all incident energy back along a parallel path. This makes three very bright spots added to the weaker general return of the other surfaces of the beam. At longer ranges the spreading of the sonar beam smears out these strong returns to form an image that looks even more like a line. Thus the apparently increased visibility of the frame at longer ranges is a result of beam-spreading. A redesign of the frame could significantly reduce its visibility.

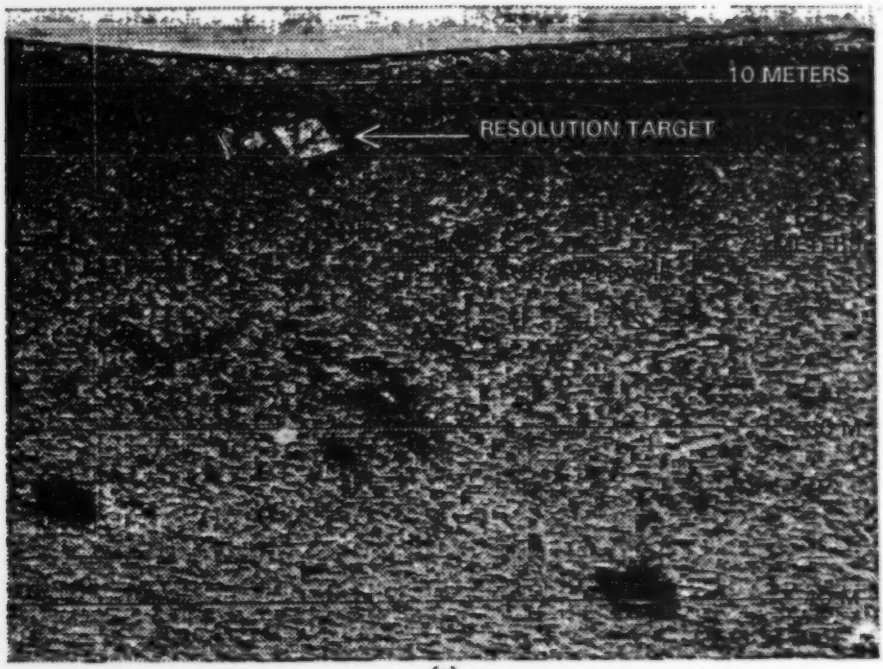


(a)



(b)

Figure 18: The Resolution Target Seen by the 117 kHz, Long-Pulse System (a) at a range setting of 100 meters, (b) at a range setting of 75 meters.



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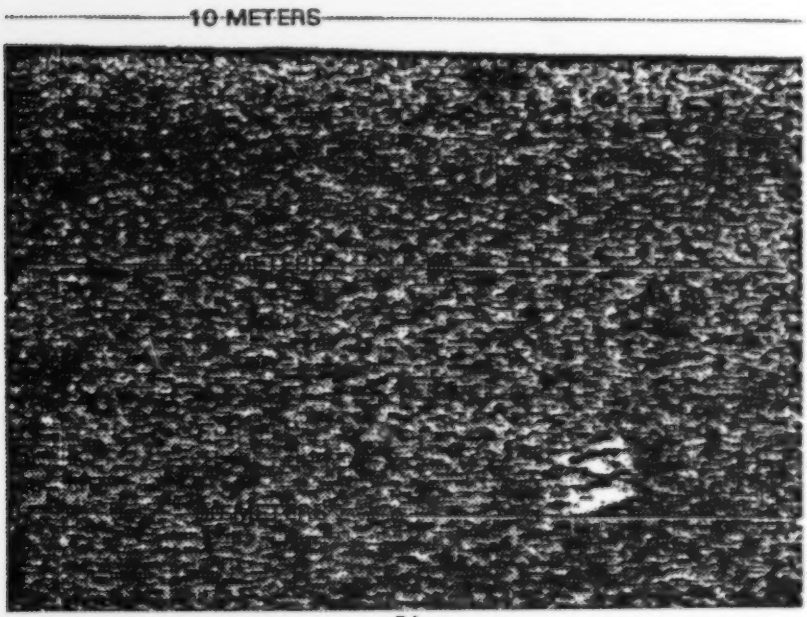
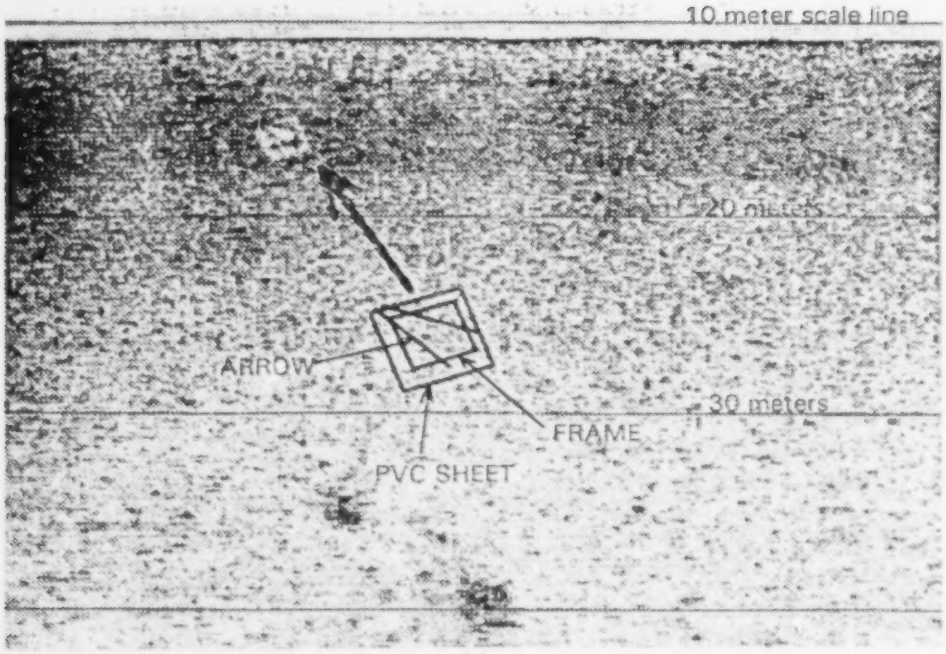
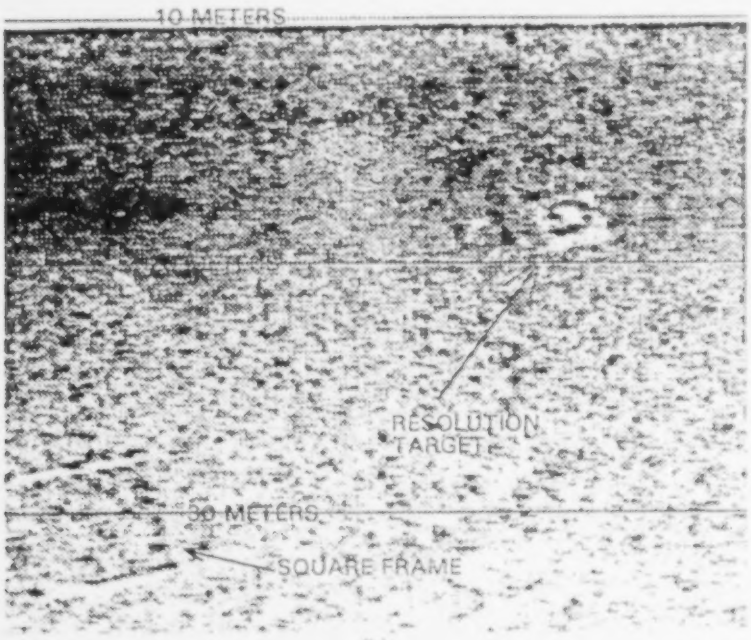


(b)

Figure 19: The Resolution Target Seen by the 117 kHz, Short-Pulse System (a) at a range setting of 100 meters, (b) at a range setting of 75 meters.

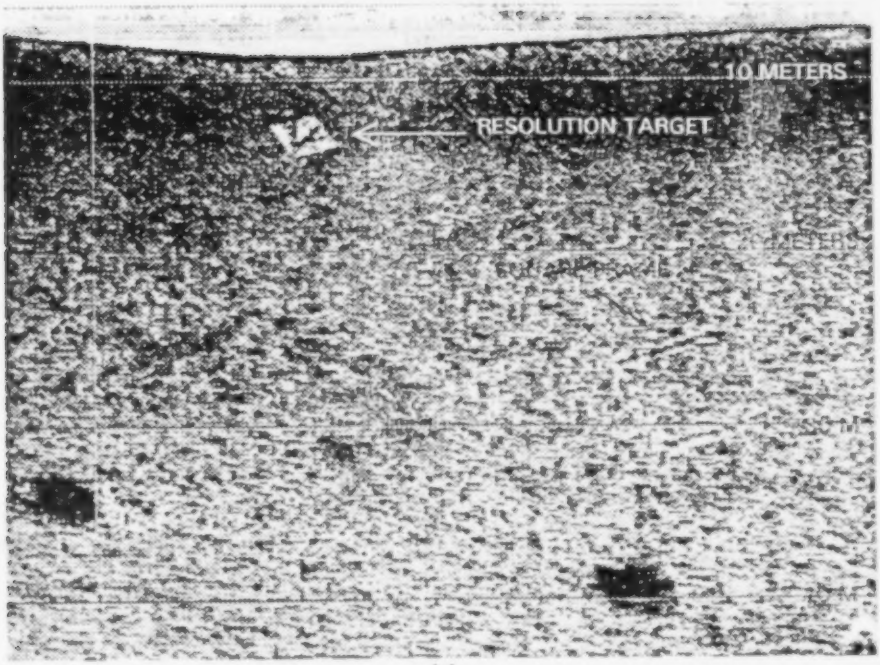


(a)

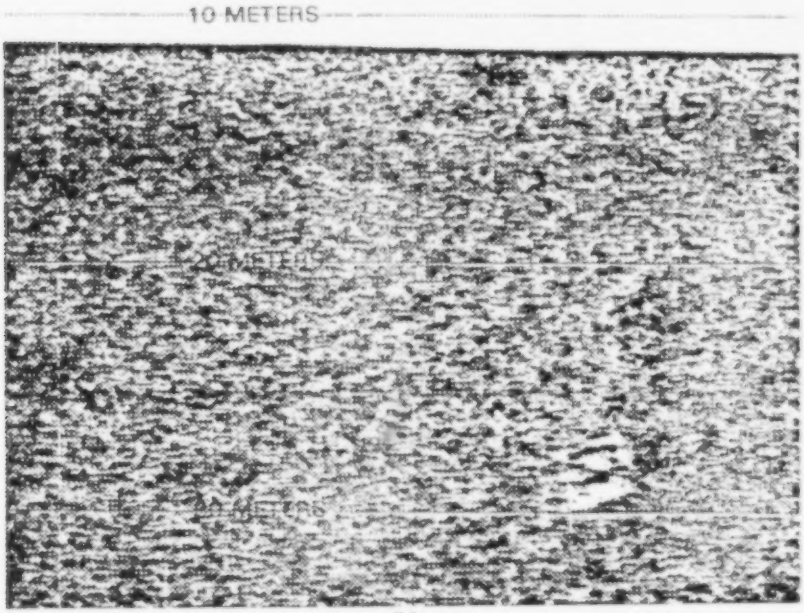


(b)

Figure 18: The Resolution Target Seen by the 117 kHz, Long-Pulse System (a) at a range setting of 100 meters, (b) at a range setting of 75 meters.



(a)



(b)

Figure 19: The Resolution Target Seen by the 117 kHz, Short-Pulse System (a) at a range setting of 100 meters, (b) at a range setting of 75 meters.

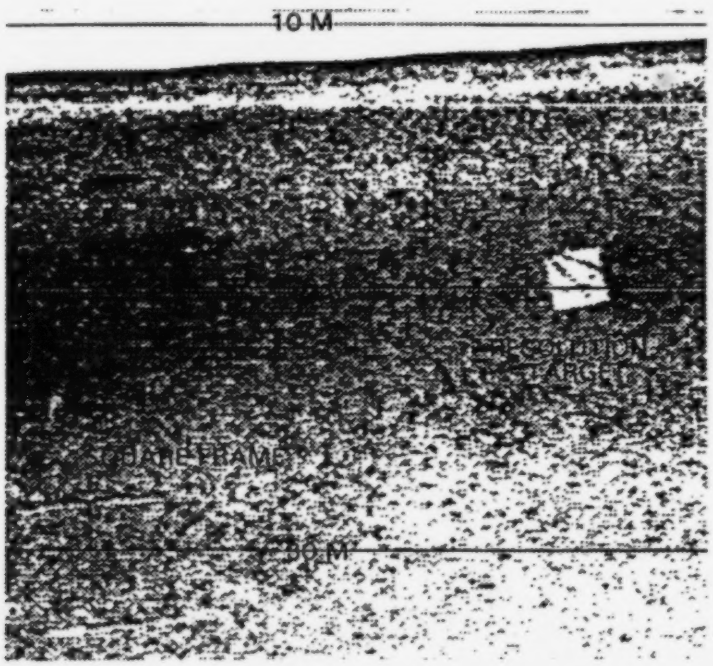


Figure 20: The Resolution Target Seen by the 350 kHz System at a range setting of 75 meters.

Studying the effect of the two pulse lengths tried with the low-frequency system, shows that images from the short-pulse system very closely resemble the results obtained with the long-pulse system. Because the resolution target images are small, and they are "noisy" because of through transmission at this frequency, and because there are other variations between images such as the distance to target and the direction of the arrow on the resolution target with respect to the track, we can see no predictable difference between the long and short pulse 117 kHz systems with the resolution target images.

The Resolution Target is extremely clear when viewed with the 350 kHz DREP/AT sonar system. The frame under the target is almost invisible, except a very small amount of energy from the aforementioned corner reflectors. The arrow is bright and distinct against a pure white background. The very narrow beam of the 350 kHz transducers in the very quiet DREP/AT sonar system gives beautiful images of the resolution target.

Ship-Wreck Targets

Ship wrecks have their value as targets also. They present strong detailed targets with large shadows, which are valuable for testing the range limits of the sonar system. This is particularly valuable in the Esquimalt area where much of the ocean floor appears to be featureless fine sand. The images shown in Figures 21 through 23 are at short-range but allow comparison to be made of the effects of sonar frequencies and pulse lengths used.

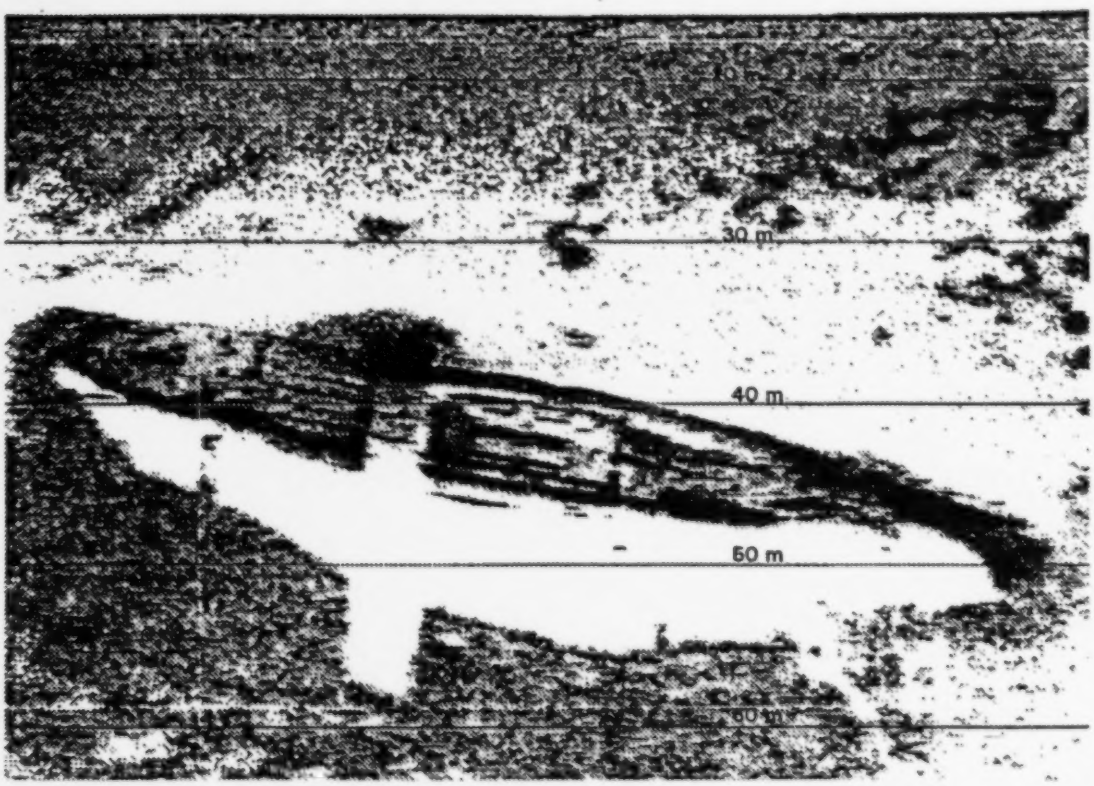


Figure 21: 55m Shipwreck Seen by the 117 kHz, Long-Pulse System

The image in Figure 21 was made with the system set to the 100 meter range, and the first visible scale line is 20 meters from the transducer. Figures 22 and 23 have maximum ranges of 75 meters, and the first visible scale line in each image is 10 meters from the transducer array.

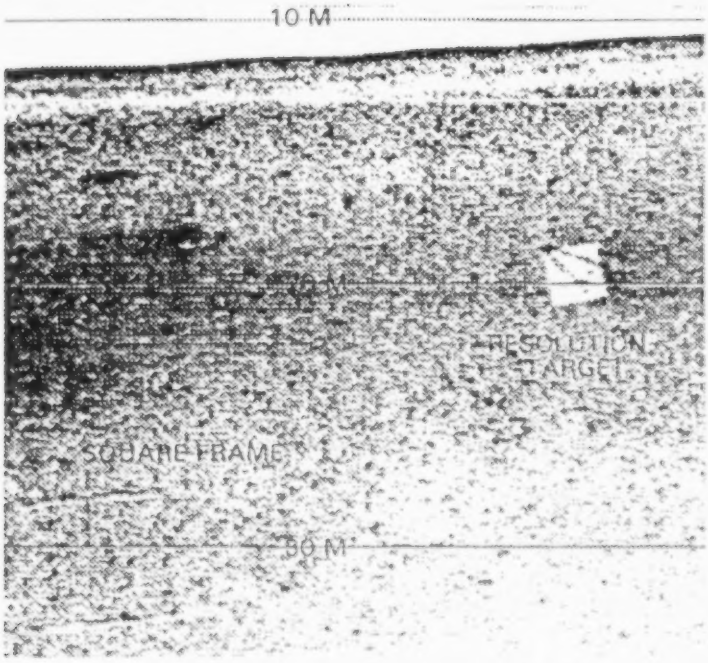


Figure 20: The Resolution Target Seen by the 350 kHz System at a range setting of 75 meters.

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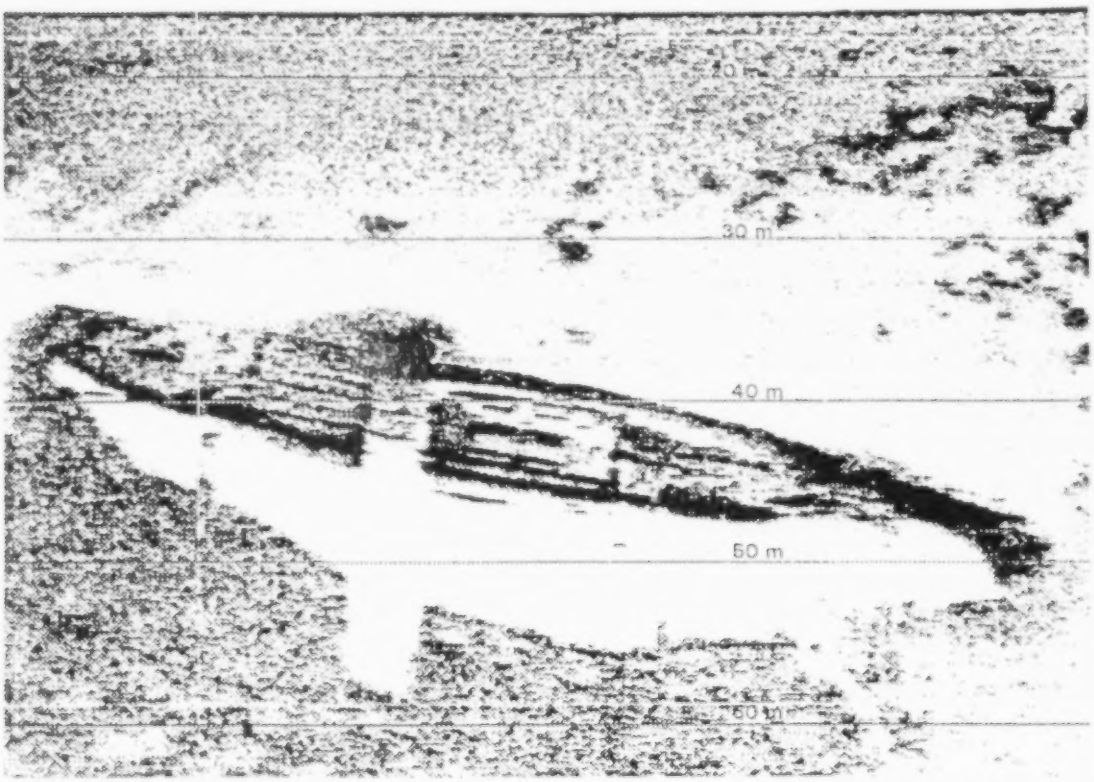

Figure 21: 55m Shipwreck Seen by the 117 kHz, Long-Pulse System

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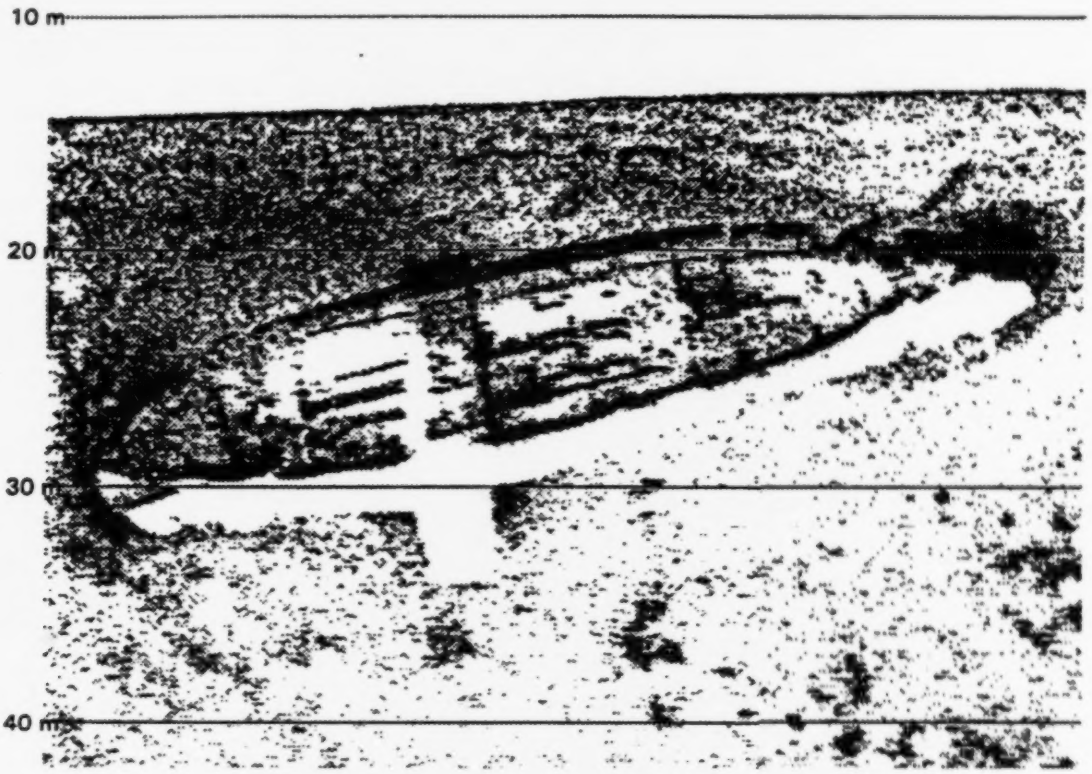

Figure 22: 55m Shipwreck Seen by the 117 kHz, Short-Pulse System

Here the short-pulse and long-pulse 117 kHz images appear different enough that it might be possible to conclude that the long-pulse system is less resolved than the short-pulse system images. The effect may be due to the difference in range, however, since beam spreading causes the signal to become less sharp as the range increases. The "long-pulse" shipwreck is forty to fifty meters from the transducer array whereas the "short-pulse" shipwreck is between 20 and 30 meters away. This makes the beam size between .6 and .9 meters for the near ship, and between 1.2 and 1.5 meters for the farther ship. So again, there are too many variables to make a conclusive decision regarding the importance of capacitor size in this circuit.

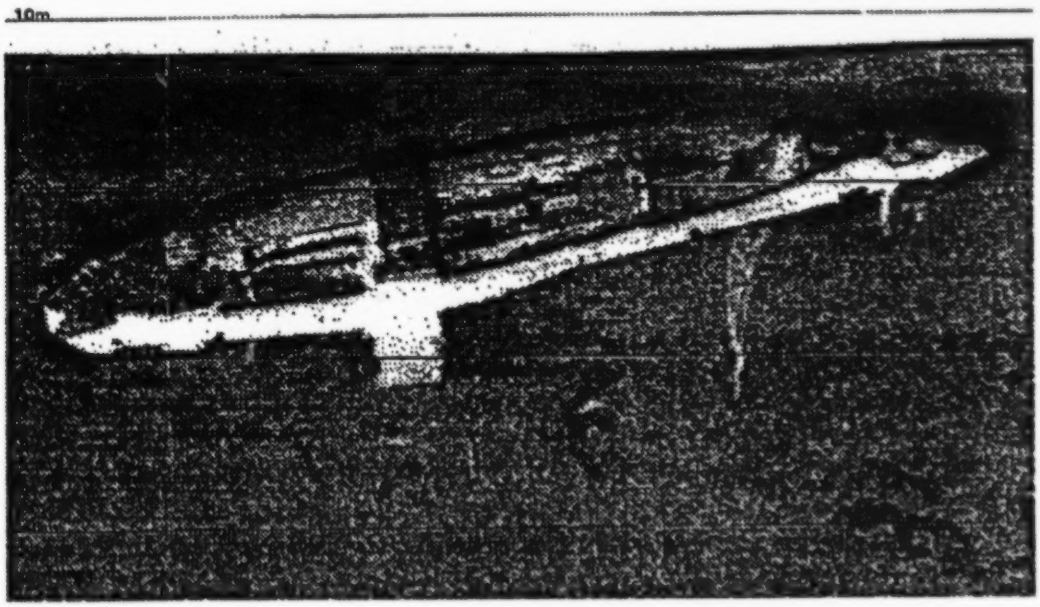

Figure 23: 55m Shipwreck Seen by the 350 kHz System

The image of the shipwreck given in Figure 23 presents a very high-resolution image, which reveals details of the wreck which are not visible in the preceding 117 kHz images. Figure 24 also shows a highly-detailed image of a different shipwreck at a much longer range taken with the 350 kHz DREP/AT sonar system. The overall range of the image is 75 meters, and the first visible scale line is 20 meters from the transducer array. Notice the clear shadow that stretches at least as far the 75 meter edge of the paper. This large target provides a good test of the system long-range abilities. The periodic fading in the last five meters of the printout is caused by printer problems, not actual signal variations.

The record in Figure 24 shows the surface return running through the target, and the noise added by the surface return thereafter. The amount of noise from the surface depends upon the roughness of the surface. Fortunately the water was fairly calm throughout these trials.

Figure 25 shows the 55m wreck again, but at 150 to 200 meters range, with the 117 kHz short-pulse system. This image was taken with the system set to 200 meters range, and the towfish was at an altitude of 30 meters. The apparent surface return at between 130 and 135 meters is not the first appearance of the surface, but is a second bounce.

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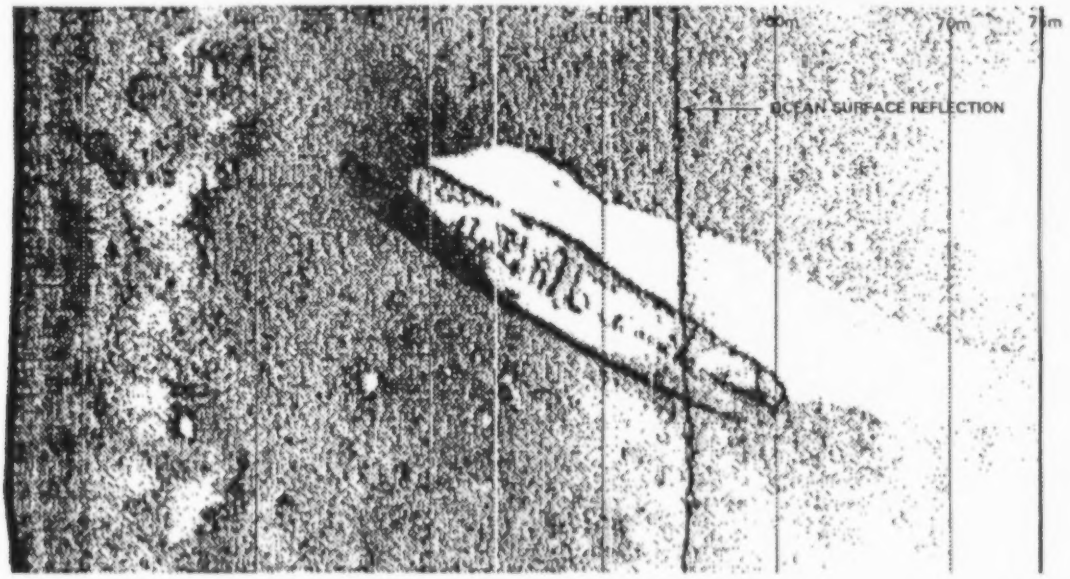

Figure 24: Distant Shipwreck Seen by the 350 kHz System

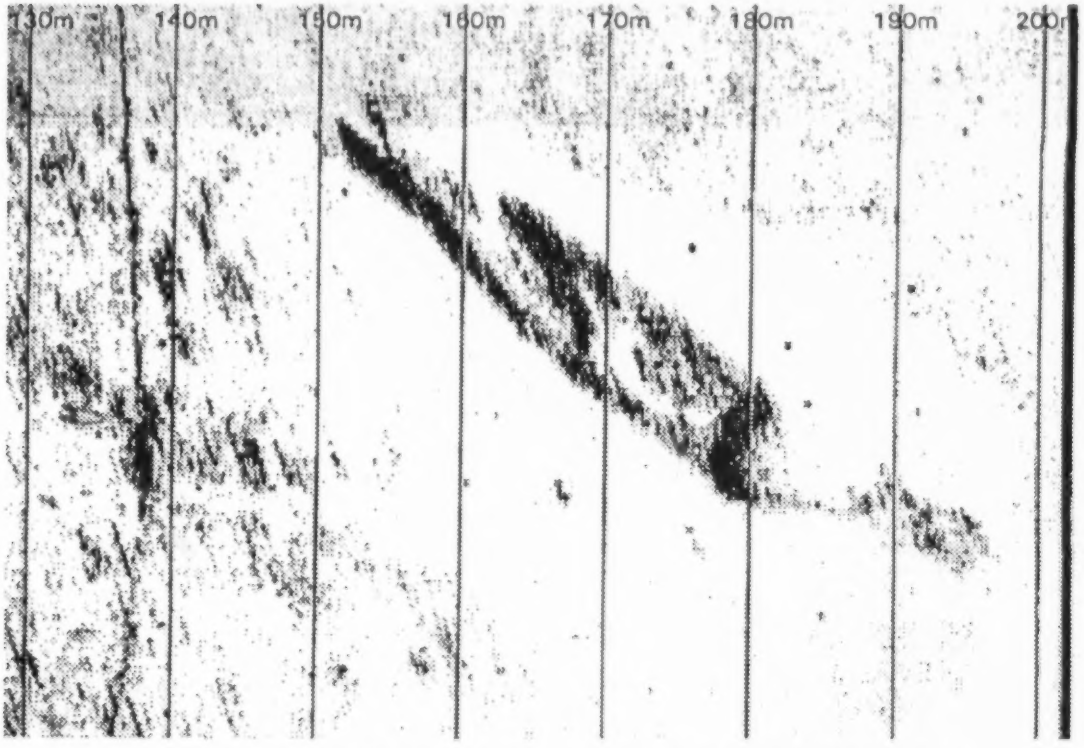

Figure 25: Distant Shipwreck Seen by the 117 kHz, Short-Pulse System

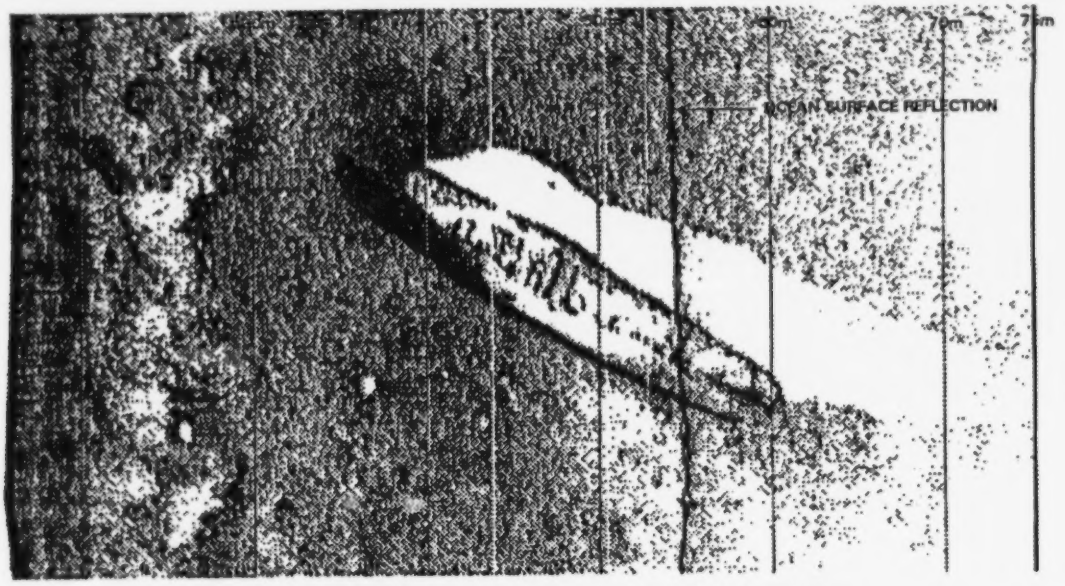

Figure 24: Distant Shipwreck Seen by the 350 kHz System

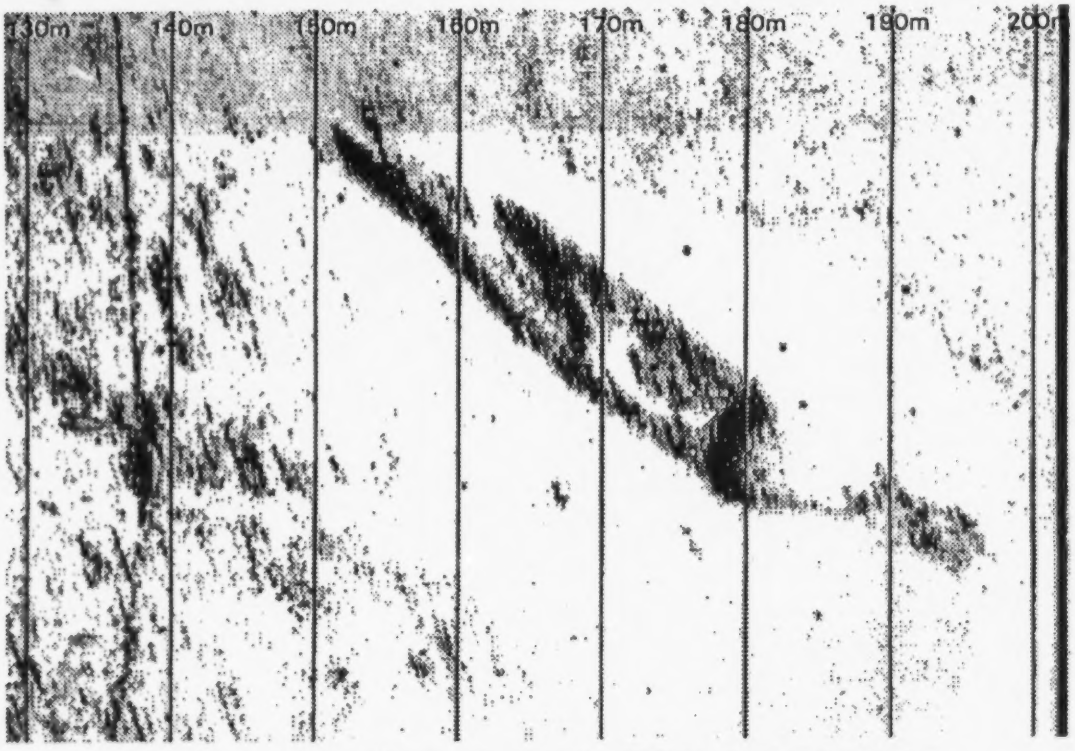

Figure 25: Distant Shipwreck Seen by the 117 kHz, Short-Pulse System

What makes this image valuable is that the ship's shadow can be distinguished from the surrounding background even at the 200 meter limit of the page. While the image is blurred because of beam spreading of the 117 kHz beam, large features are clearly discernible. This image shows that sufficient power is transmitted, even with the small transmitter capacitor, to maintain a signal-to-noise ratio that provides shadow visibility at 200 meters range. It also shows that the advantage of the low-frequency system is its ability to detect large objects at long ranges. The water transmits sound more efficiently at the lower frequency, so the range of the 350 kHz system is less than that of the 117 kHz system.

5.0 FUTURE WORK

Further modifications are being made to the system to make it smaller and quieter. The Klein 531T power supply will be replaced with individual off-the-shelf modules from various companies. The transmitter cards and the preamplifiers are being completely redesigned. The chassis is to be replaced with a shorter one made entirely of steel (except the end cap). A digital-audio-tape (DAT) recorder has been purchased for use with this system to replace the current VCR recording system. Experiments are planned for early 1994 to integrate this system with the ARCS vehicle (Autonomous and Remote Controlled Submersible) for which the sonar system is being designed.

6.0 CONCLUSIONS

The DREP/AT side-scan sonar system functions extremely well in the towed configuration producing very low-noise, high-resolution records from a low power, small-size system.

Small objects with fine details show up very well with this system, as seen in the images of the resolution target. While the beam spreading inherent in the 117 kHz arrays limit the low-frequency system's resolution, targets and shadows can, nonetheless, be clearly seen at a range of 200 meters. The high-frequency system does not suffer from beam spreading, but does experience greater signal absorption and greater noise levels. In spite of this, the 350 kHz system is very effective for viewing targets and shadows out to 75 meters.

While tests were made using two pulse lengths in the low-frequency system, there is no conclusive difference between the two. Since the longer pulse length transmits more power into the water, it is the preferred choice.

7.0 ACKNOWLEDGMENTS

The authors wish to thank Dave Berger, Deg Klektau, and Bob Chappell for technical assistance with chassis design and noise problems, as well as Woody Godlien and Darryl Gittens in the metal-working shop for chassis construction. The end-cap was designed by Dave Berger and constructed by the Ship-Repair-Unit (Pacific) Machine Shop to whom we are grateful.

References and Addresses

[1] Klein Associates, Inc., Klein Drive, Salem, New Hampshire 03079, USA, Telephone (603) 893-6131, Fax (603) 893-8807.

[2] Rempel, L.C., "Beam Pattern Calculations of the Klein Side-Scan Sonar Transducer Arrays," draft.

[3] Gandalf Data Limited, 130 Colonnade Road South, Nepean, Ontario, K2E 7J5, Canada, Telephone (613) 723-6500, Fax (613) 226-1717.

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A Modified Klein 595 Side-Scan Sonar System

4 AUTHORS (Last name, first name, middle initial)

Rempel, Laura C., and Schattschneider, George K.

5 DATE OF PUBLICATION (month and year of publication of document)

December 1993

6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.)

36

6b. NO. OF REFS (total cited document)

7 DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

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Defence Research Establishment Pacific (DREP) is developing a side-scan sonar system for use on an autonomous vehicle. A preliminary towed-body system was designed and tested in the spring and summer of 1993. It is comprised of components of the Klein 595 Digital Sonar System, most of which have been modified, and in-house components. This combination has produced a high-resolution, low-noise system which performs well as a towed side-scan sonar system. This paper describes the non-proprietary elements of the system and the modifications made to the Klein components, as well as the results of the trials.

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